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PLANT GEOGRAPHY OF NORTH CENTRAL NEW MEXICO[1]

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY 160

J. R. WATSON

(WITH SEVEN FIGURES)

The area included in this investigation comprises the northern half of New Mexico, the most detailed study having been made of Bernalillo and portions of the adjoining counties containing a section of the Rio Grande Valley and the Sandia Mountains, but the results have been confirmed by excursions to other portions of the northern half of the territory.

The 35th parallel passes through the region under consideration, which indicates a hot sun during the summer and a warm one during the winter. The altitude ranges from a little less than 5000 ft. in the valley of the Rio Grande to about 11,000 ft. on the northern part of the Sandia Range.

The topography is varied. The recent valley of the Rio Grande, occupying the center of our region, is two or three miles wide. The floor is composed of beds of a hard clay ("adobe"), sand, and gravel. The water level is here usually only a foot or two below the surface and near the river often rises above it, leaving, when the water evaporates, a crust of alkali which whitens the ground like hoar frost on a November morning. The river is a shallow, muddy stream with a fall of five feet per mile. It may be a half-mile or more wide during the June melting of the snow on the Colorado mountains, or entirely dry during August, under the combined influence of drought and the demands of the irrigation ditches above. At low water it exposes extensive mud flats on which a vigorous plant growth quickly develops.

On either side this recent valley is limited by the much dissected edge of the mesa, which rises 100–300 ft. in a mile or two. These hills, although known locally as "sand hills," may be composed of sand, hard adobe, or a clayey gravel with stones up to the size of a man's head thickly strewn over the surface; or, more usually, all of these deposited in alternate layers, showing plainly its fluviatile origin. On the west side of the valley are occasional sand dunes bearing absolutely no vegetation.

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[1] This study was undertaken under the direction of Dr. HENRY C. COWLES.

From these hills a clinoplain, known locally as "the mesa" (not a true mesa), slopes gradually upward toward the mountains with a quite uniform grade of nearly 100 ft. to the mile, although appearing to the eye to be nearly level or gently undulating. This mesa is also of stream origin, consisting of the ancient gravels and clays of the Rio Grande intermixed with sand fans and other detritus resulting from the weathering of the mountains. On the east this plain stretches for nine or ten miles to the base of the Sandia Mountains, forming one of those old western river valleys so admirably described by MacDougal.[2] Every two or three miles this mesa is crossed by a sandy "arroyo," or dry stream bed, which once or twice each summer becomes a raging torrent for an hour or two. These arroyos lie in shallow valleys, the largest, however, having banks 100 ft. or more high. Few of these arroyos reach the river proper, but spread their flood waters over the floor of the recent valley, building up fans of an alluvium-like clay at their mouths. Numerous smaller arroyos head on the "mesa" proper or on its dissected edge. A similar mesa on the west side of the valley is partly covered by a flow of lava so recent that it has suffered almost no weathering, the shallow soil that covers it, to the depth of a few inches, having been deposited by the wind. A mile or so back from its edge this lava field is surmounted by five volcanic cones, the largest being about 300 ft. high.

From the eastern mesa the Sandia and Manzano mountains rise rather abruptly, sand and gravel fans at the mouths of the cañons forming a transition. The range is a typical block mountain with the principal fault at its western edge. It is composed of Archean granites and schists, capped by a layer of Carboniferous limestone 50–200 ft. in thickness. This limestone shows a dip to the southeast of about 20°. To the east of the main ridge lie mountains of less elevation and Permian beds of red clay. Ten miles east of the Sandia Mountains the Ortiz and San Pedro mountains rise to an altitude of 8000 ft., followed by the fertile prairies of the Estancia Valley.

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[2] MacDougal, D. T., Botanical features of North American deserts. 1908.

Climate

The most important factor in the climate is aridity. The precipitation at Albuquerque averages 7.43 in. per year; that of the mountains is much greater, but unfortunately has never been measured. Perhaps 20–24 in. would be a fair approximation for the higher parts of the range. The distribution of the rainfall is also an important factor. At Albuquerque the average for ten years was as follows:[3]

Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0.48	0.33	0.22	0.26	0.69	0.35	1.43	1.07	1.7	0.77	0.46	0.31

It will be noticed that there is a rainy season beginning in July and one of less intensity in May. This is valuable to vegetation, as the bulk of the precipitation comes during the warm season.

It would appear from observation that a precipitation of less than 0.25 in. has no effect on vegetation, with the possible exception of some of the shallow-rooted grasses, as it does not penetrate the thirsty soil to a sufficient depth to reach the roots. On the other hand, much of the summer rain comes down in such a deluge that a goodly percentage runs off the mesa and especially its foothills. The distribution and the amount are both highly variable and materially influence the aspect of the vegetation from year to year. The May rains especially often fail altogether, and it is said that during a recent drought Albuquerque received not a drop of rain for thirteen months.

The distribution of the precipitation in the mountains is radically different. Judging from observation, the summer rains are about 50 per cent in excess of those at Albuquerque. But while snow is rare in the valley, the higher parts of the mountains are covered with it for a considerable part of the winter, and snowstorms frequently occur over the whole of the range and extend down some distance on the mesa. This snow, slowly melting, thoroughly saturates the soil; much more so than the often torrential rains of the summer which quickly run off. The writer has been surprised to observe how brief an influence these summer rains have on the mountain streams and springs. A day or two after a heavy shower they are nearly as low as before, although they may have poured out a deluge for an hour or two. A heavy winter snow, on the contrary, maintains a steady flow throughout most of the summer.

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[3] MAGNUSSON, C. EDW., Bull. Univ. N.M. no. 5.

TEMPERATURE

Because of its altitude and southern latitude, the climate is characterized by a comparatively low mean annual range of temperature and a high daily range. Although the thermometer is known to go to zero or below at night, the mean for January is 34° F. (MAGNUSSON, *loc. cit.*). This is due to the high temperature in the middle of the day (average maximum 46°). For July the mean is 76.4° F., the average maximum 89°,[4] and the average minimum 63.5°. The absolute maximum for the ten years was 104° F., and it has exceeded 100° F. on three different occasions. It is the occasional low temperatures which render it impossible for the larger, thicker cacti and century plants, so characteristic of southern Arizona and Mexico, to grow here. They have been planted repeatedly on the campus of the University of New Mexico, only to perish during the winter.

EVAPORATION FROM A FREE WATER SURFACE

The following data (MAGNUSSON, *loc. cit.*), giving evaporation in inches, show that the ratio of evaporation to rainfall is more than 10 to 1:

Jan.	Feb.	Mch.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2.04	2.63	6.17	6.82	10.08	12.63	11.78	10.21	8.00	4.38	1.73	1.4

Total for the year 77.87 inches.

SOIL MOISTURE

Measurements of soil moisture gave the following results: sandy soil in the valley in December (dry season) 0.8 in. below the surface, 30 per cent; sandy soil in the "highlands" (edge of the valley), 1.9 per cent; sandy clay on the mesa, 3.9–10 per cent; sandy clay in May on the mesa, 4.8–7.2 per cent.

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[4] A striking characteristic of the arid southwest is the great difference in temperature in the sun and in the shade.

CAPACITY FOR HOLDING MOISTURE

Some determinations were made to determine the capacity for holding moisture, following the method used by LIVINGSTON,[5] with the following results. In the first column is shown the per cent of water absorbed in proportion to the dry weight of the soil; while in the second column the per cent of water is calculated in terms of "wet volume," that is, the volume of the dirt when allowed to settle under water. There is practically no humus in any of the mesa soil. In the piñon association there is a little humus, in the yellow pine association more, while in the Douglas spruce there is abundant humus.

Open mesa (Gutierrezia association)	23.8 per cent	37.3 per cent
Bigelovia association (edge of mesa) where Bigelovia was most luxuriant	21.4	35.4
Hymenatherum society of the association	12.7	25.8

WIND

A factor influencing the evaporation from plants is wind. Although the average velocity is probably not great, autumn and early winter being especially calm, there occur, especially in late winter and spring, violent windstorms which pick up the sand and even pieces of gravel large enough to break the glasses of a man walking against it. These violent winds plants must encounter, and this may be the factor which prevents the growth of lichens on the rocks on the mesa. The prevailing direction of the wind is south and southwest. This seems to be the explanation of the presence of sand dunes on the western edge of the valley and their absence on the eastern side.

LIGHT

In this clear atmosphere the illumination is of course intense and very annoying to the traveler in summer. Concerning the percentage of cloudiness MAGNUSSON presents the following average for ten years: days entirely clear, 219.4; days partly clear, 104.9; days cloudy, 38.4.

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[5] LIVINGSTON, B. E., Relation of desert plants to soil moisture. BOT. GAZ. **50**: 241–256. 1910.

Plant formations and associations

Floristically the country is very interesting, as it is the meeting place of the northern and eastern flora with that of the arid southwest. On the slopes of the mountains the botanist familiar with the flora of the east would be able to recognize at least the genus of nearly every plant encountered, while upon the mesa, with the exception of *Gaura* and *Salsola*, scarcely a genus would be familiar.

RIVER VALLEY FORMATIONS

1. *Cottonwood forest*

Along the Rio Grande, where the water-table is never very far from the surface, there occurs an open and more or less pure forest of *Populus Wislizenii*. The trees are small, due probably to the operations of the native ranchers in their search for fuel and fence posts, for individual trees of this species planted in dooryards are veritable giants in girth. Scattered throughout this forest and especially along the banks of the streams are a few willows, clumps of the shrubs *Baccharis Wrightii* and *Cassia bauhinioides*, while on the ground grow *Juncus balticus*, *Trifolium Rydbergii*, *Aster spinosus*, and a little grass. This forest is monotonously uniform and poor in species.

2. *Juncus-Houttuynia association*

Alternating with the last in its possession of the river banks is a meadow-like association of which *Juncus balticus* and *Houttuynia californica* are the dominant plants. Just what factors determine which of these two associations will take possession of a given area is not clear to the writer. However, it would seem that, given time enough, the cottonwoods will occupy most of the situations. The *Juncus-Houttuynia* association, however, is not a necessary stage in the formation of a cottonwood forest, as the latter may develop directly from a mud bank. Whenever a mud bank is exposed for a few weeks in summer, a vigorous growth at once appears, of which young cottonwoods, willows, cat-tails, and cocklebnrs are the dominant species. If one looks closely, many small annuals and numerous specimens of *Riccia fluitans* are seen; but one misses the bulrushes and sedges he would find in similar places in the east. The usual fate of such young growth is to be washed away upon the return of high water, but should this fail to happen for a year or so, the young cottonwoods may be large enough to hold the soil, and a forest develops. Other characteristic plants of this association are *Baccharis Wrightii*, *Helianthus annuus*, *Dysodia papposa*, *Onagra Jamesii*, *Amorpha fruticosa*, and *Rumex Berlandieri*. In more sandy places one meets *Aster spinosus*, *Maurandia Wislizenii*, *Sesuvium sessile*, and *Cycloloma atriplicifolia*.

Much of the valley is under ditch and as a consequence does not show the characteristic vegetation, but along the ditches a dense thicket usually develops, composed of *Cassia*, willows, sunflowers, *Solidago canadensis* var. *arizonica*, and others.

3. *Bigelovia association*

On higher ground, where the water level is deeper, there is found a variety of edaphic plant associations due chiefly to differences in slope and soil and the consequent ability to hold water. But on much of this area the dominant plant is *Chrysothamnus* (*Bigelovia*) *Bigelovii*, a low shrubby perennial, almost leafless, but the green shoots retain their color throughout the year, so that in winter, when the prevailing color of the landscape is brown, this formation may be detected ten miles away. It covers most of the higher gravel beds of the valley and the dissected border of the mesa, but stops abruptly and completely at the edge of the more level mesa. With the exception of the rock surfaces of the mountains, this is the most xerophytic of all our situations; the steep clay hills quickly shed what little water falls on them. In sandy places *Yucca glauca* is fully as abundant as the *Bigelovia*, and in places where a foot or two of sand covers a stratum of adobe, the *Yucca* becomes the dominant plant. In places where the sand is deep and extensive, such as the wider valleys or arroyos, a society, of which *Parosela* (*Dalea*) *scoparia* is the abundant plant, takes possession of the soil, often to the entire exclusion of *Bigelovia*, but not of *Yucca*. This plant has slender wandlike branches which are regularly winter-killed for several inches. Other plants very abundant here are *Croton texensis*, the spiny ragweed (*Franseria acanthicarpa*), *Orobanche multiflora*, and *Cenchrus tribuloides*.

The steeper hills of this formation are too xerophytic even for *Bigelovia*, and here the low shrubby composite *Hymenatherum acerosum* is the most abundant plant. Associated with it usually are *Crassina* (*Zinnia*) *grandiflora*, *Ephedra trifurca*, whose leafless stems both look and feel like a branched *Equisetum*, and several species of *Eriogonum*. The *Crassina* has a method of seed dispersal that is not mentioned in any text with which I am familiar. The very large ligules of its ray flowers, instead of dropping off, become dry and papery, and when the seeds are ripe, the whole head separates from the stem and goes rolling off over the plain and hills, a diminutive tumbleweed.

The arroyos of this dissected edge of the mesa show an interesting succession of societies, characterized by successively smaller plants as one ascends. If sufficiently large to deposit considerable sand, their lower courses are occupied by the desert willow (*Chilopsis saligna*), a plant with pretty *Catalpa*-like blossoms. Its leaves, however, resemble very closely those of such a willow as *Salix longifolia*. It is the tallest shrub outside of the mountains and the cottonwood forest, reaching a height of 15–20 ft.

Ascending the arroyo this society is replaced by one in which *Fallugia paradoxa* is dominant. This rosaceous plant is very slow to drop its leaves, retaining them until late in the winter. It has pure white blossoms and plumose fruit. It grows to a height of 3–4 ft. in dense thickets, which are even more dense underground, where about half of the stems are found, in which respect it resembles the famous mesquite of more southern regions, the plant which gave rise to the expression that in New Mexico one "climbs for water and digs for wood." Here grow also two low perennial evergreen composites, *Berlandiera lyrata* and *Melampodium cinereum*. After the summer rains there appears here, as on the mesa, a relatively abundant growth of annuals, among which the composites *Hymenopappus flavescens*, *Thelesperma gracile*, and *Baileya multiradiata*, together with *Pentstemon ambiguus*, are characteristic.

A little higher up, where the arroyo is not over 6–8 ft. wide, the bed proper is generally free from plants except an occasional *Euphorbia*, but the banks are occupied by *Bigelovia*. Near its head, where the arroyo is only 1–2 ft. wide, its sides are occupied by a narrow fringe of shrubs, chief of which are *Parosela formosa* and *Lycium pallidum*.

In the valleys of the larger arroyos that continue the mountain streams there appears yet another society, characterized by the dominance of either *Suaeda Moquinii*, or the greasewood *Sarcobatus vermiculatus*, or both, the former being more particularly confined to the adobe fans at the mouths of the arroyos. Like so many of the shrubby plants of this region, these and especially the *Suaeda* catch the wind-blown dust and allow it to accumulate among its stems, making mounds like low sand dunes, but in this case composed of adobe. For this reason this association is covered with hummocks often 6 and sometimes 10 ft. high. This is an alkali society, due to the evaporation of the flood waters of the arroyo, and has the same relation to the arroyos as a floodplain forest to a river valley in the east. Mixed with salt grass it is the dominant association around the salt beds and lakes of the Estancia Valley, as well as along the Rio Salada branch of the Jemez River.

MESA FORMATION

This occupies the more level ground of the mesa proper and stops abruptly at its dissected edge, as stated under the last heading. This was undoubtedly originally a grassland, and is so yet where it has not been too seriously over-grazed. It should probably be classified as a steppe. Now, thanks to lack of scientific control of grazing, it has been so invaded by the composite *Gutierrezia* (a somewhat shrubby perennial that grows to be 3 ft. high, and is often called "goldenrod") as to merit being called a *Gutierrezia* formation (fig. 1). The seasons of 1909 and 1910 were drier than usual until about July 20, and as a result 90 per cent of the plants are entirely dead and most of the remainder show only a small branch or two alive. In the autumn of 1907, after an unusually wet (or less dry) season, the entire mesa was a sea of gold, but during those two years it bloomed only in the mountains and along trails where there is less crowding and where the dust of the trail conserves the moisture after the principle of dry-farming. In 1911 the summer rains commenced in late June and the plants that survived are thrifty and show abundant bloom.

The mesa is monotonously uniform, especially in winter when one may ride for miles and see only a few grasses, *Gutierrezia*, clumps of *Opuntia fragilis*, or occasionally a *Yucca glauca* or a prickly pear (*Opuntia* sp.).

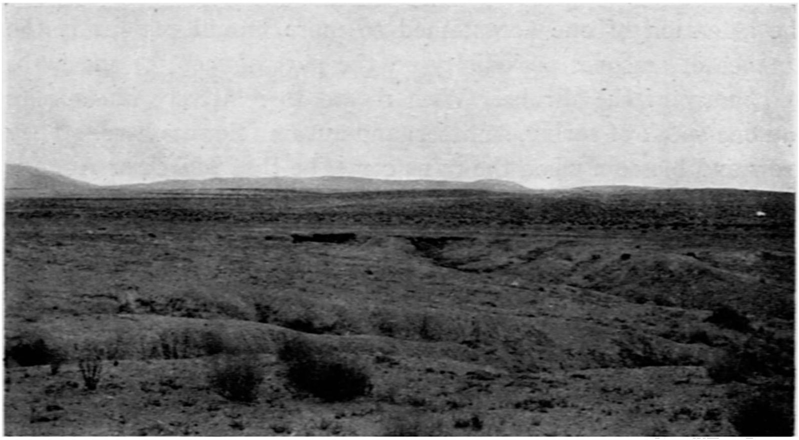

FIG. 1.—The head of an arroyo on the edge of the mesa: in the foreground, *Gutierrezia*, *Salsola*, and *Yucca glauca;* to the extreme left a clump of *Chrysothamnus Bigelovii;* in the distance the *Gutierrezia* association.

The plants of the mesa belong to three ecological groups. (1) Plants like the cacti, *Bigelovia*, *Yucca*, *Sarcobatus*, and *Suaeda*, which have large, usually underground stems or roots, in which moisture is accumulated. (2) Annuals and perennials with underground stems, including by far the largest number of individuals, but usually not the largest and most conspicuous. They are plants which are able to wait for the rains and then to make an exceedingly rapid growth and maturity. Here belong most of the mesa herbs and grasses. The latter cure perfectly *in situ* and make most excellent hay. It is this property of the grasses that makes the grazing industry possible in this country. (3) The third class includes a few plants that are winter annuals. The fall rains and the occasional snow flurries during the winter afford them sufficient water for growth in favorable situations, and they are ready to blossom with the spring rains. The most conspicuous examples in this class are *Phacelia corrugata*, some of the loco weeds (*Astragulus* sp.), *Draba*, *Gilia*, and sometimes *Gaura coccinea*, *Sideranthus spinulosus*, and many of the plants that are ordinarily summer annuals may occasionally develop during the winter and blossom with the first shower of spring or summer. Indeed, the one feature of the vegetation of this region that attracts the attention of one accustomed to more humid regions is the absence of seasonal periodicity on the part of most of the herbs and many of the shrubs. With regard to relatively few species can one speak of spring, summer, and autumn flowers here. They grow and blossom when the rains come, be that March or August. During 1909 and 1910 the rains came July 20 and July 23 respectively, and the result was that the mesa was brown and lifeless until then, but by August 1 it was a garden, nearly covered by a mat of vegetation, made up of grasses, *Abronia*, *Allionia*, *Townsendia strigosa*, *Houstonia humifusa*, *Plantago Purshii*, *Asclepias brachystephana*, *Wedelia incarnata*, Russian thistle, and *Solanum elaeagnifolium*. By September 10 all was over and the mesa had assumed its usual brown hue. Thus in six weeks the annuals and the underground perennials had grown, flowered, and matured their seeds. The exceptions to this rule are those plants in the first class, the larger shrubs, the cacti, yuccas, and other plants having thick roots or stems providing for the storage of water. With May come the blossoms of the stemless evening primroses (*Oenothera* sp.), the chimaja (*Cymopterus*), and the wild onions. When June arrives, we have the flowers of the cacti, yuccas, and the desert willow; while September brings out the blossoms of *Bigelovia* and October the *Gutierrezia*, if there has been rain. This formation and the next two are classed as Upper Sonoran by MERRIAM and his followers.

In the middle of the mesa, 15 miles to the south, the outcropping of a layer of sandstone causes a succession of springs to appear, and about these springs are cottonwoods, *Juncus*, *Houttuynia*, and other plants of the valley. In other words, a spring changes Upper

Sonoran to Lower at once. On the other hand, there appears on the rock cedars and other plants characteristic of the next formation. This association is also spread over the mesa west of the river and over the lava field where the species are identical with those of the sandy clay of the mesa, but some, especially *Gutierrezia*, are stunted. Here also are a few cedars, *Rhus*, and other mountain plants. This lava field seems to receive slightly more rainfall.

As one approaches the mountains and ascends one of the sand or gravel fans at the mouths of the cañons, a new plant appears, *Opuntia arborescens*, whose cylindrical stems, 6–8 ft. tall, bear beautiful deep rose blossoms in June, and yellow fruit the remainder of the year (figs. 2 and 3). These cacti form dense thickets, which with *Yucca glauca*, *Croton texensis*, and *Fallugia*, which again become abundant here, are quite as characteristic features of these fans as the more abundant *Gutierrezia* and grasses.

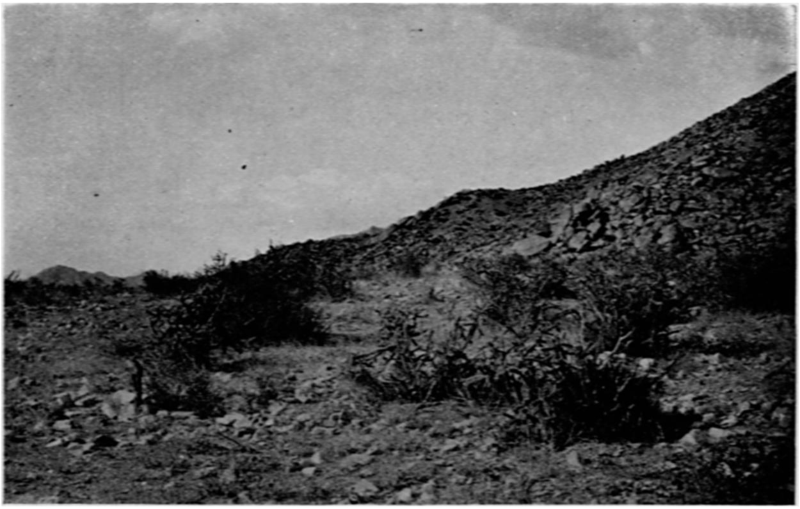

FIG. 2.—At the base of the Sandia Mountains: *Opuntia arborescens* society; *Rhus trifoliata* appears in the center, and in the background on the rocky slope are black looking clumps of *Nolina*.

CEDAR FORMATION

Next comes the formation of which *Juniperus monosperma* is the dominant plant. East of Albuquerque it is confined strictly to the mountains, but where the mesa rises higher (6500 ft. or over) it stretches out over the plains. In the Estancia Valley it seems to be spreading at the expense of the prairie, as considerable areas are dotted over with young trees where there are no signs of old ones. But in many places, as here, it clings to the rock outcrop and to the neighborhood of scattered rocks, doubtless because of the moisture conserved under them. In this connection it is interesting to recall the occasional occurrence of cedars on the lava a thousand feet lower. That the lower edge of this formation is limited by the supply of soil moisture is evident. On the whole, it coincides quite closely with the lower limit of the usual winter snow. Near the lower edge, especially, the trees are far apart, broken, stunted, gnarled, constantly recalling an old neglected orchard in a back pasture in Ohio. *Gutierrezia* and *Yucca glauca* extend into this formation and *Opuntia arborescens* is abundant

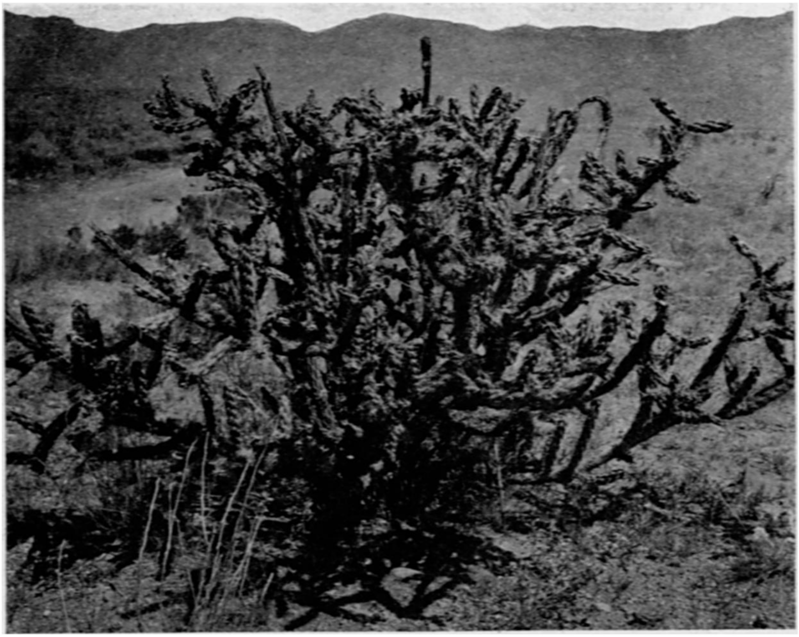

FIG. 3.—*Opuntia arborescens* in fruit: to the left is an arroyo

and characteristic. Other members are *Rhus trilobata*, *Nolina texana* (a long-leaved liliaceous evergreen), and the spiny-leaved oak, *Quercus undulatus*. The *Rhus* is also imperfectly evergreen, and indeed there is less difference between the winter and the summer aspect of this formation than of any other, because there is less difference in the relative humidity of the soil.[6]

PIÑON FORMATION

This has been combined with the last by MERRIAM and other writers, and they do shade into each other very gradually, even imperceptibly, but no more so than do the *Pinus ponderosa* and Douglas spruce formations, which are separated by these authors. Furthermore, the piñon (*Pinus edulis*) never extends as far down the mountain side as does the cedar, the differences being on the average at least 500 ft. Other plants very characteristic here are *Yucca baccata* or "amole," mountain mahogany (*Cercocarpus parvifolius*), *Philadelphus microphyllus*, *Lesquerella Engelmanni*, and *Tragia nepetaefolia*.

YELLOW PINE ASSOCIATION

This is the "transition zone" of MERRIAM, which he states is on the whole more closely related to the Sonoran than to the Boreal, a conclusion which seems to the writer to be incorrect at least so far as plants and insects are concerned. The latter are treated in another publication.[7] The characteristic plants, after the *Pinus ponderosa scopulorum*, are *Geranium atropurpureum*, white oaks, red cedar (*Juniperus scopulorum*), the pasque flower (*Anemone patens Nuttalliana*), wild gooseberry (*Ribes divaricatum irriguum*), *Ptelea mollis*, wild grape (*Vitis arizonica*), cudweed (*Antennaria plantaginifolia*), and New Jersey tea (*Ceanothus Fendleri*). Here occurs a sharp and complete change of flora. There is much more difference between this formation (fig. 4) and the mesa or even the piñon formation less than a mile away, than there is between it and the woods of Ohio, as witness the preceding genera, if not species.

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[6] Whether the oaks and *Rhus* drop their leaves early in the winter or carry them until spring is determined by the soil moisture. In less dry winters and along arroyos they retain them. Under more xerophytic circumstances the leaves are dropped.

[7] Report of the N.M. Resource and Conservation Commission. December 1911.

Here is a most interesting tension line between the flora of the arid southwest and the more humid north.

The association descends in some places to 7000 ft., and extends to the top of the range at 10,000 ft., and coincides very closely with the region of deep winter snow. On the western slope its aspect is somewhat different from that of the eastern slope. On the former it reaches its best development in amphitheater-like U-shaped valleys, which collect the winter snow and practically protect the trees from the drying winds and sun of summer. These areas I have called "pine parks." On the east slope, with its greater precipitation, the forests are more extensive and possess a flora which reminds one very forcibly of that of the pine forests of Kentucky, especially where there has been a fire. The dominant

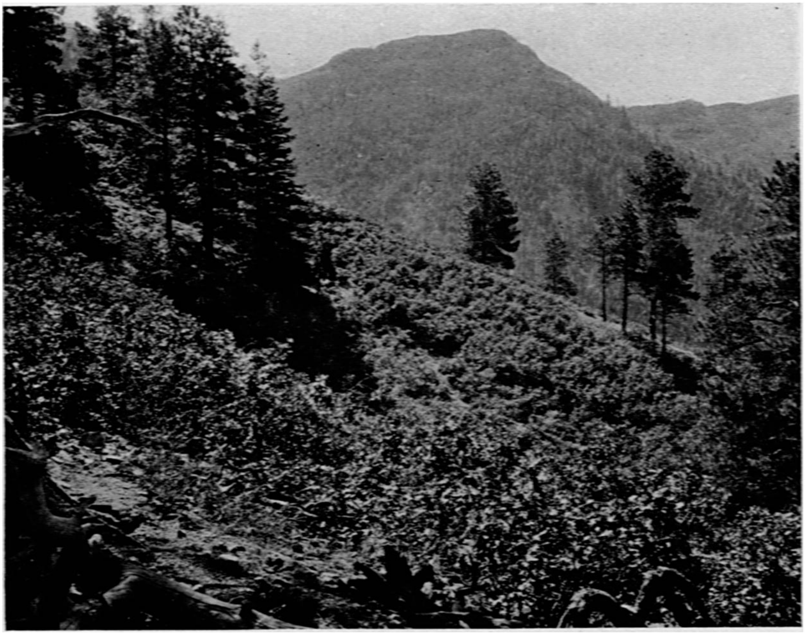

FIG. 4.—View toward the south in the Sandia Mountains (about 8500 ft.) in the yellow pine association: in the foreground the oak chaparral (*Quercus* sp. and *Robinia neo-mexicana*) and yellow pine, and to left of center a Douglas spruce; in the distance, covering a north-facing slope, is the Douglas spruce association.

grasses here, as there, are species of *Andropogon*, and mixed with them are *Liatris punctata*, *Ratibida columnaris pulcherrima*, and *Zygadenus*.

In places along streams charged with lime the red cedar often takes almost entire possession of the soil, forming a quite distinct association.

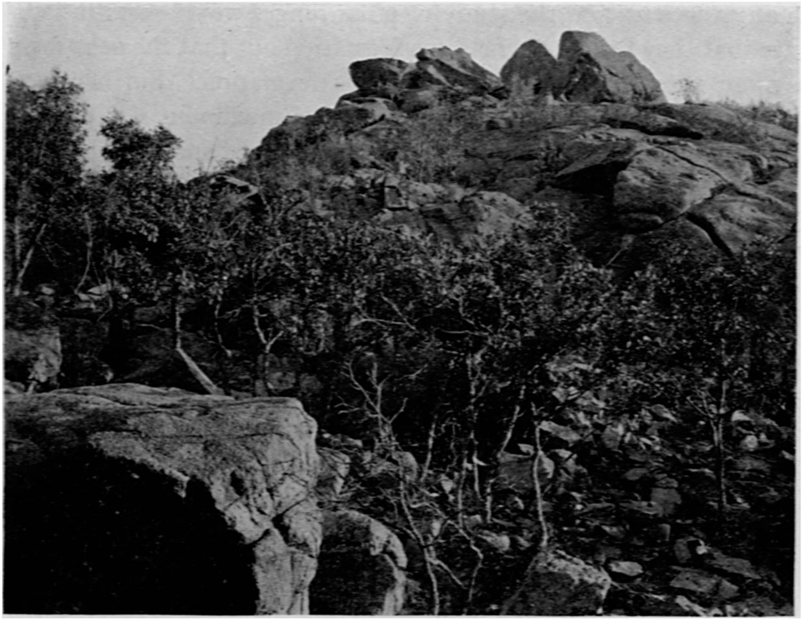

FIG. 5.—Top of Sandia Mountains: white oaks occupying a depression where they are sheltered from wind.

In the Sandia Mountains the white oaks are very characteristic of this formation, but in the more mesophytic Jemez Mountains, and also on Mt. Taylor, where the yellow pine grows even more luxuriantly, there is much less oak, and MERRIAM states that none was seen on the San Francisco Mountains, although COWLES reports its occurrence upon the southern slopes. The explanation of this varying amount of pine and oak is to be found in the fact that the oak is able to grow in more xerophytic situations than the pine (fig. 5). It, with *Robinia neo-mexicana* and bearberry

(*Symphoricarpus rotundifolius*), forms a dense and almost impenetrable chaparral 4–5 ft. high, which covers the highest, steepest slopes, and the wind-swept and therefore xerophytic mountain tops. In these parts of the range there is very little pine or spruce, except on north-facing slopes, and from a study of the Sandia Mountains alone one would be tempted to place the oaks in a separate formation; but there are clumps of oak among the pine in all situations, and the study of other ranges would seem to indicate that they belong to the same formation but that the oaks form a more xerophytic association in this formation. Furthermore, both the oaks and the locusts reach their maximum size only in the more mesophytic places among the pines and spruces.

The herbs of this association are also somewhat different. Conspicuous are several species of *Pentstemon*, *Campanula rotundifolia*, *Ceanothus Fendleri*, *Thalictrum Fendleri*, and somewhat less common are *Hedeoma Drummondii*, *Gentiana affinis*, and *Calochortus Gunnisonii*.

In the Manzano Mountains the alligator juniper is common in what is chiefly the *Pinus-Andropogon* association, but having some elements of the piñon formation. This would seem to be about the northern limit of *Juniperus pachyphloea*, as it is entirely absent from the Sandia Mountains.

Mountain meadows

In places (usually saddles) on the top of the range, the chaparral gives place to a meadow-like growth, composed, however, not chiefly of grasses, but of low herbs, *Potentilla*, *Castilleja*, *Brickellia*, *Chrysopsis villosa*, *Aphanostephus humilis*, *Gymnolomia multiflora*, *Actinella acaulis*, *Achillea lanosa*, *Oxytropis Lamberti*, *Allium stellatum*, and cacti of the genera *Mamillaria*, *Cereus*, and *Echinocactus*.

These open places are small, the largest being about a half-mile long, and they occupy the less xerophytic situations. They are sufficiently numerous to enable one to walk with comparative ease along the summit of the range, dodging from one to another and thus avoiding most of the chaparral.

DOUGLAS SPRUCE FORMATION

Covering north-facing slopes above 8000 ft. and extending down the narrower cañons to about 7000 ft., we have a formation of which the Douglas spruce (*Pseudotsuga taxifolia*) is the dominant tree (fig. 6). This is the most mesophytic and dense of all our forests. Here occur the blue and Canada violets, *Berberis aquifolium* (*repens*), *Galium* sp., *Monarda fistulosa*, *Mertensia oblongifolia*, *Polemonium foliosissimum*, *Pachystima myrsinites*, *Oxalis violacea*, *Prunus demissa*, *Fragaria*, *Rosa arkansana*, *Amelanchier alnifolia*, *Heuchera parvifolia*, *Sedum Wrightii*, *Corydalis aurea*, *Clematis* (*alpina*) *occidentalis*, *Aquilegia canadensis*, *Stellaria Jamesii*, and *Smilacina stellata*. This is the "Canadian zone" of MERRIAM, but nowhere in this locality does it make a complete belt around the mountains. It occurs in its full development only in the most mesophytic places, as in the narrower V-shaped cañons and on north-facing slopes where snow accumulates in huge drifts

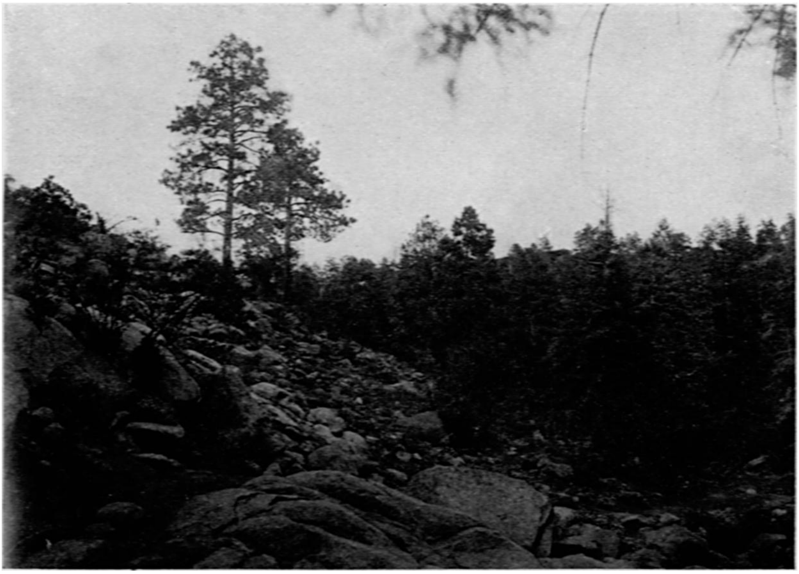

FIG. 6.—In the cañon the Douglas spruce association; on the rocky slope the *Pinus ponderosa* association; in the foreground, white oaks, verbena (in bloom), and mountain mahogany; a small red cedar to the right of the rocks in the center.

during the winter, but scattering trees, dwarfed and stunted, rise from the chaparral over most of the summits of the range mixed with the yellow pine, especially at lower levels, and with the blue spruce (*Abies concolor*) at higher. On North Sandia Mountain, which, on account of its greater elevation and perhaps more east and west trend, has a higher precipitation, the latter tree forms almost pure forests. On the ground in its shade is a luxuriant and in places an almost pure growth of *Goodyera Menziesii*.

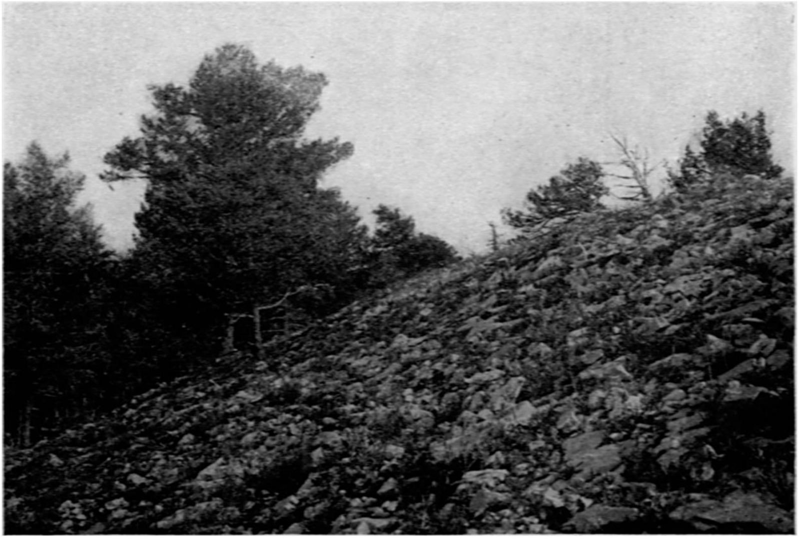

FIG. 7.—Top of North Sandia Mountain: *Picea Engelmannii*; in the foreground, *Potentilla*, *Castilleja*, and *Aphanostephus*.

On the very highest and most exposed part of North Mountain the first are replaced by Engelmann's spruce (fig. 7). This would place it in MERRIAM's "Hudsonian zone," and it is so mapped. On these heights one meets an occasional *Pinus flexilis*.

CAÑON ASSOCIATIONS

Ascending a cañon a very interesting succession of associations presents itself. The first tree met approaching the mountains from one of the arroyos is the hackberry (*Celtis reticulata*), usually only a few scattered trees or a clump here and there. Next comes a society dominated by box-elders, also rather scattered, and with considerable grape (*Vitis arizonica*). These seem to be the cañon representatives of the cedar and piñon formations respectively.

Higher up and in the narrower, more mesophytic portions of the cañon there occurs a society dominated by *Populus angustifolia*. This corresponds with the pine formation on the whole, and if the cañon is open or U-shaped, the yellow pine will occupy the floor with the poplar along the stream. Ascending still higher, where the cañon becomes decidedly V-shaped, the Douglas spruce formation holds full sway. And as one nears the head, above the permanent stream there usually occurs an association of quaking aspens, somewhat less mesophytic than the Douglas spruce formation. In the shade of the aspens grow *Rubus deliciosus*, *Osmorrhiza nuda*, *Saxifraga bronchialis*, *Jamesia americana*, *Delphinium scopulorum*, *Actaea spicata*, *Pedicularis procera*, *Frasera speciosa*, and nearly always young spruces. After a fire in the Douglas spruce the quaking aspen always takes possession, but it has also its natural place as a transition between the oak chaparral and the Douglas spruce in the biotic succession.

The biotic succession in the Sandia Mountains is as follows: the bare rock first incrusted with crustose lichens, then foliose lichens, mosses, herbs, oaks, followed in some cases directly by Douglas spruce and in others by aspen and then the spruce; and then as physiographic succession comes in, the poplars, pines, and box-elders in the cañon; and pine, piñon, and cedar on the slopes, until the ultimate formation of the mesa is reached.[8]

Response to climatic factors

This complex of associations is of course due to a complex of causes, of which the most important are relative humidity of the air and more especially that of the soil, and not the average temperature of the growing or any other season, as some eminent authorities have maintained. Temperature, of course, is a factor, but principally as it affects the humidity. I have mentioned the inability to grow certain cacti because of the winter's cold. There are narrow cañons in the lower parts of the mountains which would doubtless be occupied by Douglas spruce were they situated at a greater elevation, chiefly because of the greater precipitation. On the other hand, most of the trees of the mountains are growing on the campus of the University of New Mexico at an elevation of only 5200 ft., but they are carefully irrigated, and the Douglas spruces are in the shade of cottonwoods. The storksbill (*Erodium cicutarium*) grows in the mountain cañons and at an elevation of 5000 ft. in the valley. In the former situations it is in blossom nearly all winter, often directly beside a snowbank, and doubtless because of the snowbank, while those in the valley do not bloom until the May or July rains.

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[8] A study of Mt. Taylor indicates that the alligator juniper has a place between the yellow pine and the piñon.

Fallugia paradoxa is a most interesting plant in this regard. As mentioned above, it is a very characteristic plant in the arroyos of the mesa and its edge down to less than 5000 ft. It grows at a lower altitude than this farther south, and doubtless would here were there lower altitudes. Now these arroyos are the hottest places in this region. Their sands reflect the desert sun's glare and the banks obstruct the breeze. Yet this same *Fallugia* forms thickets on the Sandia Mountains at an elevation of over 9000 ft. on steep slopes facing the southwest, and it grows at all altitudes between. On a basis of temperature control, this distribution seems inexplicable. But these arroyos are the least xerophytic places on the mesa. The soil at the depth of a foot or two is always moist, due to the fact that the arroyo brings down a flood of water two or three times each summer and the sand conserves this and the rain most thoroughly. On the contrary, those steep southwestern slopes are the most xerophytic places in the mountains, with the exception of course of bare rock. But on account of greater rainfall, these most xerophytic places of the mountains are about as moist as the least xerophytic places on the mesa, and *Fallugia paradoxa* occupies both situations.

On an ascent of the mountains made on May 8, 1910, the oaks in the lower parts of the cañons were found in full leaf, and their blossoms gone; a little higher they were just leaving out and blossoming; at the top of the range not a bud had started. Again, on October 6 the leaves were still green and vigorous at the base, but on the summit brown and frost-killed. Thus it is seen that the growing season is at least a month shorter on the summit, but the same oaks grow in both situations.

Another illustration of the influences of moisture is seen along the Jemez River. This fair-sized stream comes roaring down off the Jemez Plateau through a rather shallow cañon which faces the south. This (altitude 6000–7000 ft.) is occupied by the Douglas spruce formation, but the slopes on each side are occupied by piñon, the yellow pine being largely omitted. The branches of the spruce and piñon are in places at the same level and subject to the same hot sun and consequently the same temperature, but the roots of the Douglas spruces have access to the unfailing water supply of the stream.

This tendency of the "Canadian zone" to creep down the cañons and of the Sonoran to ascend the ridges is noted by MERRIAM, but is explained as due to warm and cool winds, vertical exposure to the sun, etc. It receives a much simpler explanation in that the ridges are more xerophytic than the cañons. At night, when a plant is supposed to make a goodly share of its growth, these ridges are little if any warmer than the adjacent cañons. They are subject to greater and more sudden changes of temperature, to drying winds, and are less able to hold their moisture—*they are more xerophytic.*[9]

In most situations in the Sandia Mountains the oaks of the transition zone entirely surround the colonies of the Douglas spruce (Canadian zone). In watching the Sandia Mountains during four winters I have been struck by the very close correlation between the lower limit of the average winter heavy snow and that of the lower limit of the yellow pine. I believe that it is chiefly these snows that determine the distribution of this tree. Far be it from me to maintain that the temperature has no effect on the plants of this region. I am simply contending that in this arid region, at least, water is more important. Any scheme for mapping "life zones" should be based on all the factors determining the same and not on one alone.

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[9] This same tendency is seen in the Rio Grande Valley, where occur many eastern and northern genera and even species (as *Aster*, *Solidago*, *Cassia*, etc.) which are absent from the higher but drier mesa.

Light also is of course a factor even with the plants of the mesa. I tried to grow some *Yucca* and *Fallugia* in the slight shade of some box-elder trees, but they all died. It is probable that light is quite as important indirectly through its acceleration of transpiration as directly through its relation to photosynthesis.

Furthermore, these different factors may be of a very diverse importance in different groups. What may be an effective barrier for one form of life may have little influence on others. The sum total of heat during the season of reproduction may well be more of a barrier to mammals than to plants. BANKS has remarked in a recent publication that it would seem to be necessary to have a different arrangement of zones for at least every family of insects.

Summary

1. In North Central New Mexico the arid climate of the southwest meets (in the mountains) the more humid one of the north and east.

2. Corresponding with this abrupt change of climate there is an abrupt change of plant life.

3. The genera and some of the species of the mountains are identical with those of the east; those of the mesa are entirely different. There is a greater difference between the flora of the yellow pine association and that of the mesa, less than a mile away, than between the former and Ohio and probably even Europe or Japan.

4. The chief factor determining this change is moisture, the supply of which is largely determined by precipitation, ability to hold it, and protection from drying winds and sun, as shown by the following facts:

a) The same plants (*Fallugia*, *Erodium*, oaks) occur throughout a great range of altitude and temperature, but in soil of about the same degree of humidity.

b) Spruces and piñons will grow with their branches almost touching if the roots of the former have access to an unfailing water supply.

c) A spring will change "Upper Sonoran" to "Lower Sonoran."

d) Plants as *Erodium* or *Draba* bloom much earlier in the cooler but moister mountains than on the warm but arid plain.

e) A patch of mesophytic spruces ("Canadian zone") is very frequently entirely surrounded by the more xerophytic oaks of the "Transition zone."

f) The tendency of the higher zones to creep down the cañons and of the lower zones to creep up the ridges receives a much more plausible explanation in connection with the supply of moisture in the two situations, than through the cooling effects of descending currents and the warming effects of ascending ones.

5. An arrangement of "zones" should be based on all factors determining the distribution of life and not on one only, especially in a region where that one is of secondary importance.

6. Most of the plants of the mesa do not show the marked seasonal periodicity of the east.

7. Plants having large organs for the storage of moisture do show seasonal periodicity.

8. A characteristic of much of the vegetation is the ability to lie dormant until the rains come, and then to make an exceedingly rapid growth and reproduction.

9. The differences in amount and distribution of rainfall in different years causes a more marked response in plants (shown by height and reproductive activities) than in more humid regions.

10. The region is a particularly good one in which to study physiographic plant ecology because of the abrupt differences in physiography and climate.

UNIVERSITY OF NEW MEXICO
ALBUQUERQUE